Chapter 5

Sensation and Perception

Figure 5.1 If you were standing in the midst of this street scene, you would be absorbing and processing numerous pieces of sensory input. (credit: modification of work by Cory Zanker)

Chapter Outline

5.1 Sensation versus Perception
5.2 Waves and Wavelengths
5.3 Vision
5.4 Hearing
5.5 The Other Senses
5.6 Gestalt Principles of Perception

Introduction

Imagine standing on a city street corner. You might be struck by movement everywhere as cars and people go about their business, by the sound of a street musician's melody or a horn honking in the distance, by the smell of exhaust fumes or of food being sold by a nearby vendor, and by the sensation of hard pavement under your feet.

We rely on our sensory systems to provide important information about our surroundings. We use this information to successfully navigate and interact with our environment so that we can find nourishment, seek shelter, maintain social relationships, and avoid potentially dangerous situations. But while sensory information is critical to our survival, there is so much information available at any given time that we would be overwhelmed if we were forced to attend to all of it. In fact, we are aware of only a fraction of the sensory information taken in by our sensory systems at any given time.

This chapter will provide an overview of how sensory information is received and processed by the nervous system and how that affects our conscious experience of the world. We begin by learning the distinction between sensation and perception. Then we consider the physical properties of light and sound stimuli, along with an overview of the basic structure and function of the major sensory systems. The chapter will close with a discussion of a historically important theory of perception called the Gestalt theory. This theory attempts to explain some underlying principles of perception.

5.1 Sensation versus Perception

Learning Objectives

By the end of this section, you will be able to:

- Distinguish between sensation and perception
- Describe the concepts of absolute threshold and difference threshold
- Discuss the roles attention, motivation, and sensory adaptation play in perception

SENSATION

What does it mean to sense something? Sensory receptors are specialized neurons that respond to specific types of stimuli. When sensory information is detected by a sensory receptor, **sensation** has occurred. For example, light that enters the eye causes chemical changes in cells that line the back of the eye. These cells relay messages, in the form of action potentials (as you learned when studying biopsychology), to the central nervous system. The conversion from sensory stimulus energy to action potential is known as **transduction**.

You have probably known since elementary school that we have five senses: vision, hearing (audition), smell (olfaction), taste (gustation), and touch (somatosensation). It turns out that this notion of five senses is oversimplified. We also have sensory systems that provide information about balance (the vestibular sense), body position and movement (proprioception and kinesthesia), pain (nociception), and temperature (thermoception).

The sensitivity of a given sensory system to the relevant stimuli can be expressed as an absolute threshold. **Absolute threshold** refers to the minimum amount of stimulus energy that must be present for the stimulus to be detected 50% of the time. Another way to think about this is by asking how dim can a light be or how soft can a sound be and still be detected half of the time. The sensitivity of our sensory receptors can be quite amazing. It has been estimated that on a clear night, the most sensitive sensory cells in the back of the eye can detect a candle flame 30 miles away (Okawa & Sampath, 2007). Under quiet conditions, the hair cells (the receptor cells of the inner ear) can detect the tick of a clock 20 feet away (Galanter, 1962).

It is also possible for us to get messages that are presented below the threshold for conscious awareness—these are called **subliminal messages**. A stimulus reaches a physiological threshold when it is strong enough to excite sensory receptors and send nerve impulses to the brain: This is an absolute threshold. A message below that threshold is said to be subliminal: We receive it, but we are not consciously aware of it. Over the years there has been a great deal of speculation about the use of subliminal messages in advertising, rock music, and self-help audio programs. Research evidence shows that in laboratory settings, people can process and respond to information outside of awareness. But this does not mean that we obey these messages like zombies; in fact, hidden messages have little effect on behavior outside the laboratory (Kunst-Wilson & Zajonc, 1980; Rensink, 2004; Nelson, 2008; Radel, Sarrazin, Legrain, & Gobancé, 2009; Loersch, Durso, & Petty, 2013).

Absolute thresholds are generally measured under incredibly controlled conditions in situations that are optimal for sensitivity. Sometimes, we are more interested in how much difference in stimuli is required to detect a difference between them. This is known as the **just noticeable difference (jnd)** or **difference threshold**. Unlike the absolute threshold, the difference threshold changes depending on the stimulus intensity. As an example, imagine yourself in a very dark movie theater. If an audience member were to receive a text message on her cell phone which caused her screen to light up, chances are that many people would notice the change in illumination in the theater. However, if the same thing happened in a brightly lit arena during a basketball game, very few people would notice. The cell phone brightness does not change, but its ability to be detected as a change in illumination varies dramatically between the two contexts. Ernst Weber proposed this theory of change in difference threshold in the 1830s, and it has

This content is available for free at http://legacy.cnx.org/content/col11629/1.4

become known as Weber's law: The difference threshold is a constant fraction of the original stimulus, as the example illustrates.

PERCEPTION

While our sensory receptors are constantly collecting information from the environment, it is ultimately how we interpret that information that affects how we interact with the world. **Perception** refers to the way sensory information is organized, interpreted, and consciously experienced. Perception involves both bottom-up and top-down processing. **Bottom-up processing** refers to the fact that perceptions are built from sensory input. On the other hand, how we interpret those sensations is influenced by our available knowledge, our experiences, and our thoughts. This is called **top-down processing**.

One way to think of this concept is that sensation is a physical process, whereas perception is psychological. For example, upon walking into a kitchen and smelling the scent of baking cinnamon rolls, the *sensation* is the scent receptors detecting the odor of cinnamon, but the *perception* may be "Mmm, this smells like the bread Grandma used to bake when the family gathered for holidays."

Although our perceptions are built from sensations, not all sensations result in perception. In fact, we often don't perceive stimuli that remain relatively constant over prolonged periods of time. This is known as **sensory adaptation**. Imagine entering a classroom with an old analog clock. Upon first entering the room, you can hear the ticking of the clock; as you begin to engage in conversation with classmates or listen to your professor greet the class, you are no longer aware of the ticking. The clock is still ticking, and that information is still affecting sensory receptors of the auditory system. The fact that you no longer perceive the sound demonstrates sensory adaptation and shows that while closely associated, sensation and perception are different.

There is another factor that affects sensation and perception: attention. Attention plays a significant role in determining what is sensed versus what is perceived. Imagine you are at a party full of music, chatter, and laughter. You get involved in an interesting conversation with a friend, and you tune out all the background noise. If someone interrupted you to ask what song had just finished playing, you would probably be unable to answer that question.

LINK TO LEARNING

See for yourself how inattentional blindness works by checking out this **selective attention test (http://openstaxcollege.org/l/blindness)** from Simons and Chabris (1999).

One of the most interesting demonstrations of how important attention is in determining our perception of the environment occurred in a famous study conducted by Daniel Simons and Christopher Chabris (1999). In this study, participants watched a video of people dressed in black and white passing basketballs. Participants were asked to count the number of times the team in white passed the ball. During the video, a person dressed in a black gorilla costume walks among the two teams. You would think that someone would notice the gorilla, right? Nearly half of the people who watched the video didn't notice the gorilla at all, despite the fact that he was clearly visible for nine seconds. Because participants were so focused on the number of times the white team was passing the ball, they completely tuned out other visual information. Failure to notice something that is completely visible because of a lack of attention is called **inattentional blindness**.

In a similar experiment, researchers tested inattentional blindness by asking participants to observe images moving across a computer screen. They were instructed to focus on either white or black objects,

disregarding the other color. When a red cross passed across the screen, about one third of subjects did not notice it (**Figure 5.2**) (Most, Simons, Scholl, & Chabris, 2000).

Figure 5.2 Nearly one third of participants in a study did not notice that a red cross passed on the screen because their attention was focused on the black or white figures. (credit: Cory Zanker)

Motivation can also affect perception. Have you ever been expecting a really important phone call and, while taking a shower, you think you hear the phone ringing, only to discover that it is not? If so, then you have experienced how motivation to detect a meaningful stimulus can shift our ability to discriminate between a true sensory stimulus and background noise. The ability to identify a stimulus when it is embedded in a distracting background is called **signal detection theory**. This might also explain why a mother is awakened by a quiet murmur from her baby but not by other sounds that occur while she is asleep. Signal detection theory has practical applications, such as increasing air traffic controller accuracy. Controllers need to be able to detect planes among many signals (blips) that appear on the radar screen and follow those planes as they move through the sky. In fact, the original work of the researcher who developed signal detection theory was focused on improving the sensitivity of air traffic controllers to plane blips (Swets, 1964).

Our perceptions can also be affected by our beliefs, values, prejudices, expectations, and life experiences. As you will see later in this chapter, individuals who are deprived of the experience of binocular vision during critical periods of development have trouble perceiving depth (Fawcett, Wang, & Birch, 2005). The shared experiences of people within a given cultural context can have pronounced effects on perception. For example, Marshall Segall, Donald Campbell, and Melville Herskovits (1963) published the results of a multinational study in which they demonstrated that individuals from Western cultures were more prone to experience certain types of visual illusions than individuals from non-Western cultures, and vice versa. One such illusion that Westerners were more likely to experience was the Müller-Lyer illusion (**Figure 5.3**): The lines appear to be different lengths, but they are actually the same length.

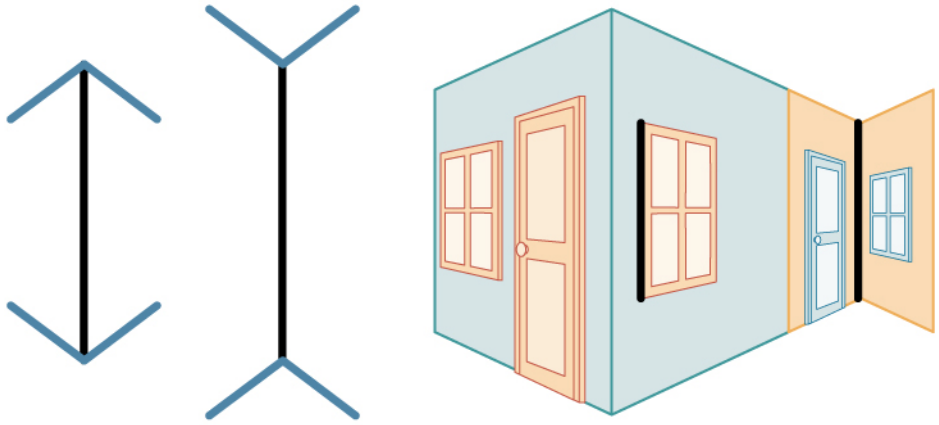

Figure 5.3 In the Müller-Lyer illusion, lines appear to be different lengths although they are identical. (a) Arrows at the ends of lines may make the line on the right appear longer, although the lines are the same length. (b) When applied to a three-dimensional image, the line on the right again may appear longer although both black lines are the same length.

These perceptual differences were consistent with differences in the types of environmental features experienced on a regular basis by people in a given cultural context. People in Western cultures, for example, have a perceptual context of buildings with straight lines, what Segall's study called a carpentered world (Segall et al., 1966). In contrast, people from certain non-Western cultures with an uncarpentered view, such as the Zulu of South Africa, whose villages are made up of round huts arranged in circles, are less susceptible to this illusion (Segall et al., 1999). It is not just vision that is affected by cultural factors. Indeed, research has demonstrated that the ability to identify an odor, and rate its pleasantness and its intensity, varies cross-culturally (Ayabe-Kanamura, Saito, Distel, Martínez-Gómez, & Hudson, 1998).

Children described as thrill seekers are more likely to show taste preferences for intense sour flavors (Liem, Westerbeek, Wolterink, Kok, & de Graaf, 2004), which suggests that basic aspects of personality might affect perception. Furthermore, individuals who hold positive attitudes toward reduced-fat foods are more likely to rate foods labeled as reduced fat as tasting better than people who have less positive attitudes about these products (Aaron, Mela, & Evans, 1994).

5.2 Waves and Wavelengths

Learning Objectives

By the end of this section, you will be able to:

- Describe important physical features of wave forms
- Show how physical properties of light waves are associated with perceptual experience
- Show how physical properties of sound waves are associated with perceptual experience

Visual and auditory stimuli both occur in the form of waves. Although the two stimuli are very different in terms of composition, wave forms share similar characteristics that are especially important to our visual and auditory perceptions. In this section, we describe the physical properties of the waves as well as the perceptual experiences associated with them.

AMPLITUDE AND WAVELENGTH

Two physical characteristics of a wave are amplitude and wavelength (Figure 5.4). The **amplitude** of a wave is the height of a wave as measured from the highest point on the wave (**peak** or **crest**) to the lowest point on the wave (**trough**). **Wavelength** refers to the length of a wave from one peak to the next.

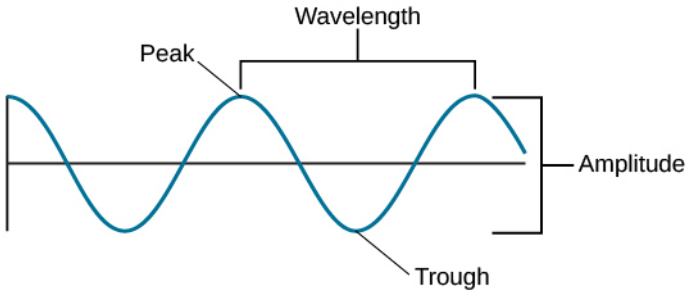

Figure 5.4 The amplitude or height of a wave is measured from the peak to the trough. The wavelength is measured from peak to peak.

Wavelength is directly related to the frequency of a given wave form. **Frequency** refers to the number of waves that pass a given point in a given time period and is often expressed in terms of **hertz (Hz)**, or cycles per second. Longer wavelengths will have lower frequencies, and shorter wavelengths will have higher frequencies (Figure 5.5).

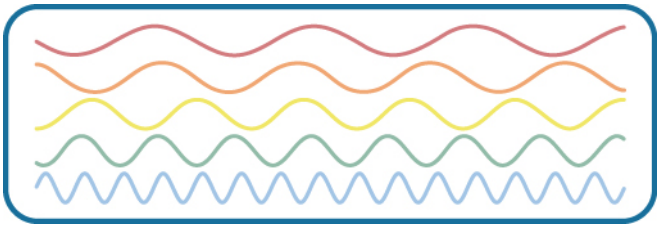

Figure 5.5 This figure illustrates waves of differing wavelengths/frequencies. At the top of the figure, the red wave has a long wavelength/short frequency. Moving from top to bottom, the wavelengths decrease and frequencies increase.

LIGHT WAVES

The **visible spectrum** is the portion of the larger **electromagnetic spectrum** that we can see. As Figure 5.6 shows, the electromagnetic spectrum encompasses all of the electromagnetic radiation that occurs in our environment and includes gamma rays, x-rays, ultraviolet light, visible light, infrared light, microwaves, and radio waves. The visible spectrum in humans is associated with wavelengths that range from 380 to 740 nm—a very small distance, since a nanometer (nm) is one billionth of a meter. Other species can detect other portions of the electromagnetic spectrum. For instance, honeybees can see light in the ultraviolet range (Wakakuwa, Stavenga, & Arikawa, 2007), and some snakes can detect infrared radiation in addition to more traditional visual light cues (Chen, Deng, Brauth, Ding, & Tang, 2012; Hartline, Kass, & Loop, 1978).

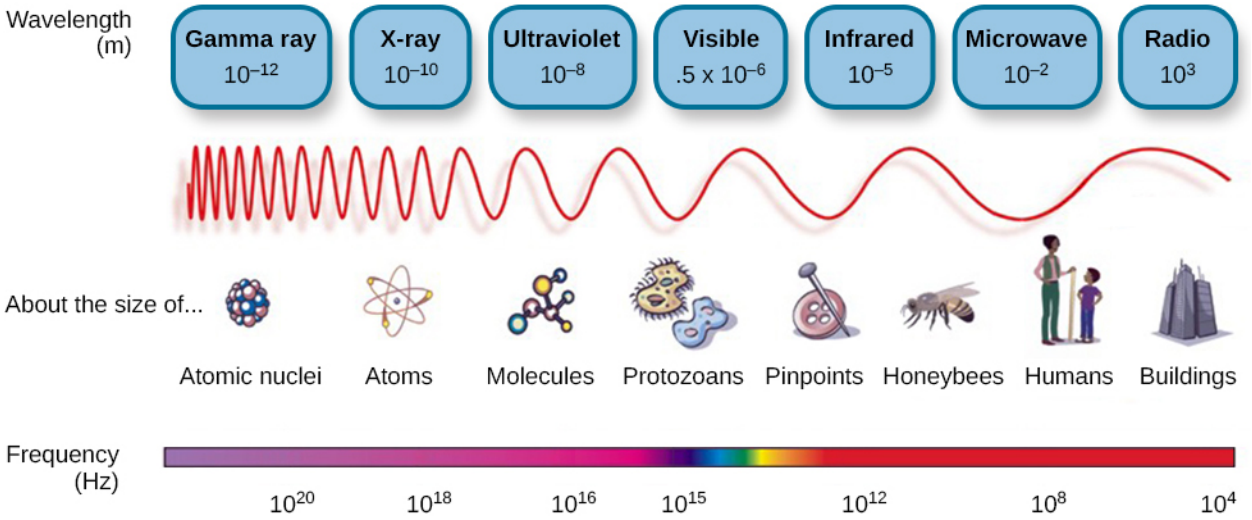

Figure 5.6 Light that is visible to humans makes up only a small portion of the electromagnetic spectrum.

In humans, light wavelength is associated with perception of color (**Figure 5.7**). Within the visible spectrum, our experience of red is associated with longer wavelengths, greens are intermediate, and blues and violets are shorter in wavelength. (An easy way to remember this is the mnemonic ROYGBIV: **r**ed, **o**range, **y**ellow, **g**reen, **b**lue, **i**ndigo, **v**iolet.) The amplitude of light waves is associated with our experience of brightness or intensity of color, with larger amplitudes appearing brighter.

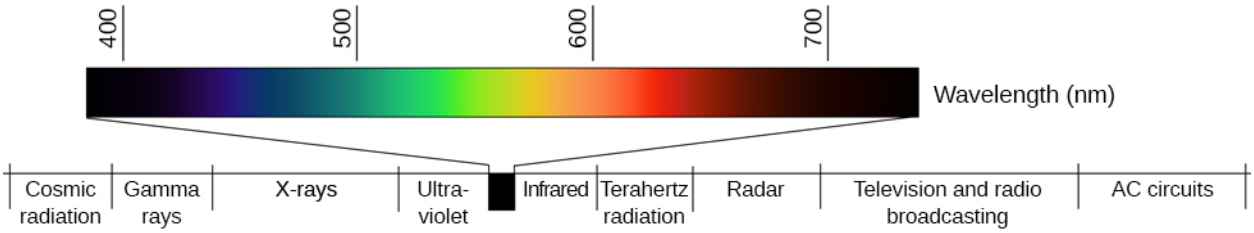

Figure 5.7 Different wavelengths of light are associated with our perception of different colors. (credit: modification of work by Johannes Ahlmann)

SOUND WAVES

Like light waves, the physical properties of sound waves are associated with various aspects of our perception of sound. The frequency of a sound wave is associated with our perception of that sound's **pitch**. High-frequency sound waves are perceived as high-pitched sounds, while low-frequency sound waves are perceived as low-pitched sounds. The audible range of sound frequencies is between 20 and 20000 Hz, with greatest sensitivity to those frequencies that fall in the middle of this range.

As was the case with the visible spectrum, other species show differences in their audible ranges. For instance, chickens have a very limited audible range, from 125 to 2000 Hz. Mice have an audible range from 1000 to 91000 Hz, and the beluga whale's audible range is from 1000 to 123000 Hz. Our pet dogs and cats have audible ranges of about 70–45000 Hz and 45–64000 Hz, respectively (Strain, 2003).

The loudness of a given sound is closely associated with the amplitude of the sound wave. Higher amplitudes are associated with louder sounds. Loudness is measured in terms of **decibels (dB)**, a logarithmic unit of sound intensity. A typical conversation would correlate with 60 dB; a rock concert might check in at 120 dB (**Figure 5.8**). A whisper 5 feet away or rustling leaves are at the low end of our hearing range; sounds like a window air conditioner, a normal conversation, and even heavy traffic or a vacuum cleaner are within a tolerable range. However, there is the potential for hearing damage from

about 80 dB to 130 dB: These are sounds of a food processor, power lawnmower, heavy truck (25 feet away), subway train (20 feet away), live rock music, and a jackhammer. The threshold for pain is about 130 dB, a jet plane taking off or a revolver firing at close range (Dunkle, 1982).

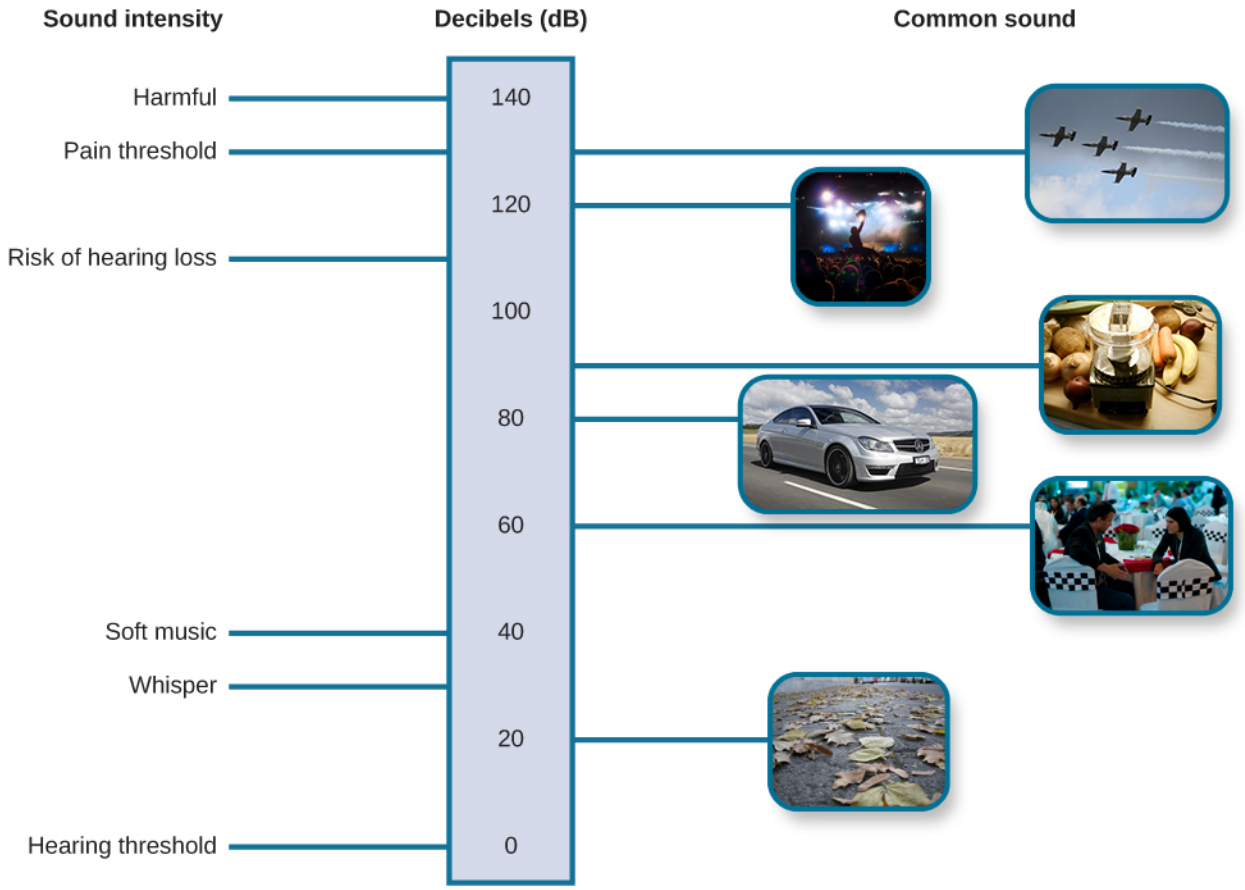

Figure 5.8 This figure illustrates the loudness of common sounds. (credit "planes": modification of work by Max Pfandl; credit "crowd": modification of work by Christian Holmér; credit "blender": modification of work by Jo Brodie; credit "car": modification of work by NRMA New Cars/Flickr; credit "talking": modification of work by Joi Ito; credit "leaves": modification of work by Aurelijus Valeiša)

Although wave amplitude is generally associated with loudness, there is some interaction between frequency and amplitude in our perception of loudness within the audible range. For example, a 10 Hz sound wave is inaudible no matter the amplitude of the wave. A 1000 Hz sound wave, on the other hand, would vary dramatically in terms of perceived loudness as the amplitude of the wave increased.

LINK TO LEARNING

Watch this **brief video (http://openstaxcollege.org/l/frequency)** demonstrating how frequency and amplitude interact in our perception of loudness.

Of course, different musical instruments can play the same musical note at the same level of loudness, yet they still sound quite different. This is known as the timbre of a sound. **Timbre** refers to a sound's purity, and it is affected by the complex interplay of frequency, amplitude, and timing of sound waves.

LINK TO LEARNING

Watch this **video (http://openstaxcollege.org/l/soundwaves)** that provides additional information on sound waves.

5.3 Vision

Learning Objectives

By the end of this section, you will be able to:

- Describe the basic anatomy of the visual system
- Discuss how rods and cones contribute to different aspects of vision
- Describe how monocular and binocular cues are used in the perception of depth

The visual system constructs a mental representation of the world around us (**Figure 5.9**). This contributes to our ability to successfully navigate through physical space and interact with important individuals and objects in our environments. This section will provide an overview of the basic anatomy and function of the visual system. In addition, we will explore our ability to perceive color and depth.

Figure 5.9 Our eyes take in sensory information that helps us understand the world around us. (credit "top left": modification of work by "rajkumar1220"/Flickr"; credit “top right”: modification of work by Thomas Leuthard; credit “middle left”: modification of work by Demietrich Baker; credit “middle right”: modification of work by "kaybee07"/Flickr; credit “bottom left”: modification of work by "Isengardt"/Flickr; credit “bottom right”: modification of work by Willem Heerbaart)

ANATOMY OF THE VISUAL SYSTEM

The eye is the major sensory organ involved in vision (**Figure 5.10**). Light waves are transmitted across the cornea and enter the eye through the pupil. The **cornea** is the transparent covering over the eye. It serves as a barrier between the inner eye and the outside world, and it is involved in focusing light waves that enter the eye. The **pupil** is the small opening in the eye through which light passes, and the size of the pupil can change as a function of light levels as well as emotional arousal. When light levels are low, the pupil will become dilated, or expanded, to allow more light to enter the eye. When light levels are high, the pupil will constrict, or become smaller, to reduce the amount of light that enters the eye. The pupil’s size is controlled by muscles that are connected to the **iris**, which is the colored portion of the eye.

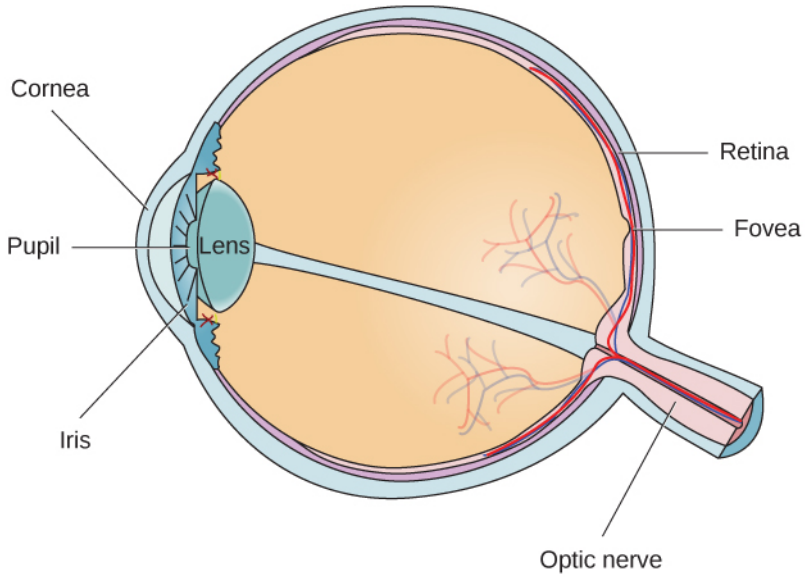

Figure 5.10 The anatomy of the eye is illustrated in this diagram.

After passing through the pupil, light crosses the **lens**, a curved, transparent structure that serves to provide additional focus. The lens is attached to muscles that can change its shape to aid in focusing light that is reflected from near or far objects. In a normal-sighted individual, the lens will focus images perfectly on a small indentation in the back of the eye known as the **fovea**, which is part of the **retina**, the light-sensitive lining of the eye. The fovea contains densely packed specialized photoreceptor cells (**Figure 5.11**). These **photoreceptor** cells, known as cones, are light-detecting cells. The **cones** are specialized types of photoreceptors that work best in bright light conditions. Cones are very sensitive to acute detail and provide tremendous spatial resolution. They also are directly involved in our ability to perceive color.

While cones are concentrated in the fovea, where images tend to be focused, rods, another type of photoreceptor, are located throughout the remainder of the retina. **Rods** are specialized photoreceptors that work well in low light conditions, and while they lack the spatial resolution and color function of the cones, they are involved in our vision in dimly lit environments as well as in our perception of movement on the periphery of our visual field.

This content is available for free at http://legacy.cnx.org/content/col11629/1.4

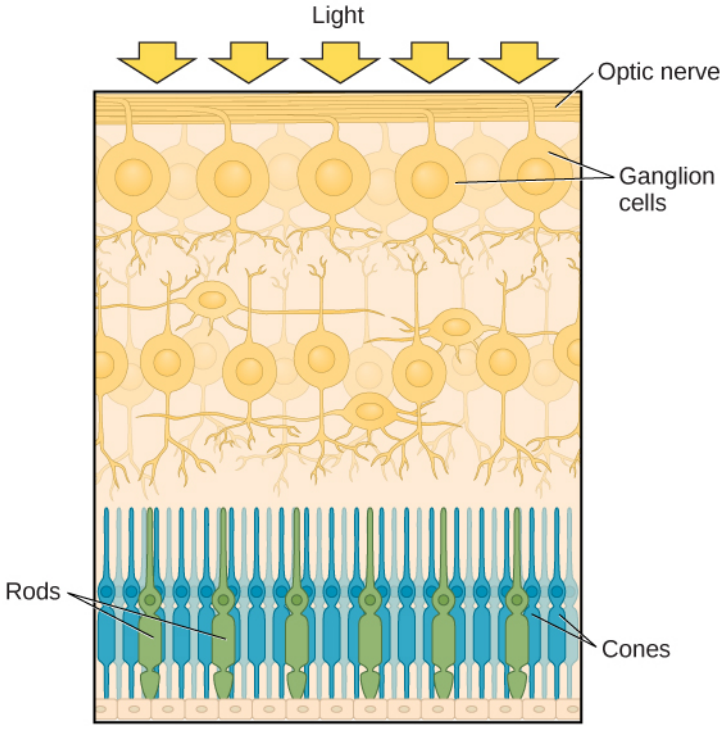

Figure 5.11 The two types of photoreceptors are shown in this image. Rods are colored green and cones are blue.

We have all experienced the different sensitivities of rods and cones when making the transition from a brightly lit environment to a dimly lit environment. Imagine going to see a blockbuster movie on a clear summer day. As you walk from the brightly lit lobby into the dark theater, you notice that you immediately have difficulty seeing much of anything. After a few minutes, you begin to adjust to the darkness and can see the interior of the theater. In the bright environment, your vision was dominated primarily by cone activity. As you move to the dark environment, rod activity dominates, but there is a delay in transitioning between the phases. If your rods do not transform light into nerve impulses as easily and efficiently as they should, you will have difficulty seeing in dim light, a condition known as night blindness.

Rods and cones are connected (via several interneurons) to retinal ganglion cells. Axons from the retinal ganglion cells converge and exit through the back of the eye to form the **optic nerve**. The optic nerve carries visual information from the retina to the brain. There is a point in the visual field called the **blind spot**: Even when light from a small object is focused on the blind spot, we do not see it. We are not consciously aware of our blind spots for two reasons: First, each eye gets a slightly different view of the visual field; therefore, the blind spots do not overlap. Second, our visual system fills in the blind spot so that although we cannot respond to visual information that occurs in that portion of the visual field, we are also not aware that information is missing.

The optic nerve from each eye merges just below the brain at a point called the **optic chiasm**. As **Figure 5.12** shows, the optic chiasm is an X-shaped structure that sits just below the cerebral cortex at the front of the brain. At the point of the optic chiasm, information from the right visual field (which comes from both eyes) is sent to the left side of the brain, and information from the left visual field is sent to the right side of the brain.

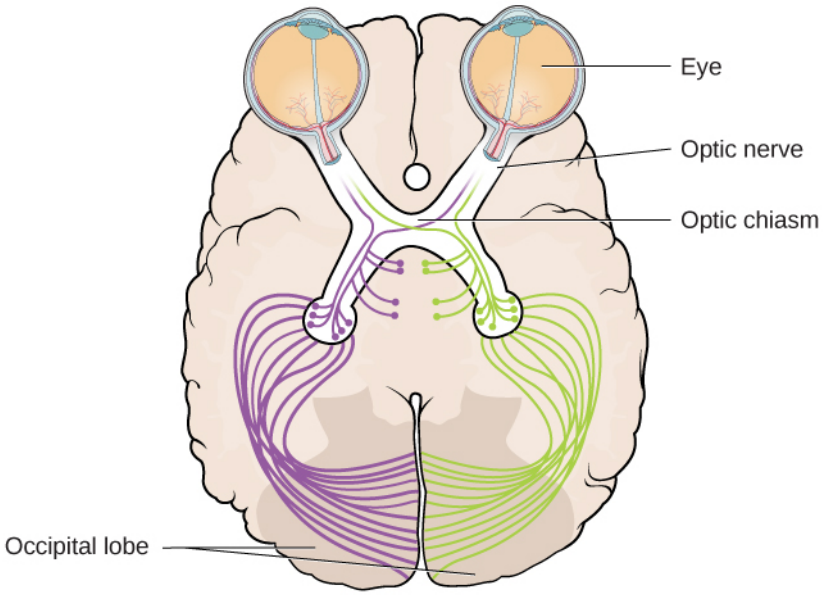

Figure 5.12 This illustration shows the optic chiasm at the front of the brain and the pathways to the occipital lobe at the back of the brain, where visual sensations are processed into meaningful perceptions.

Once inside the brain, visual information is sent via a number of structures to the occipital lobe at the back of the brain for processing. Visual information might be processed in parallel pathways which can generally be described as the "what pathway" and the "where/how" pathway. The "what pathway" is involved in object recognition and identification, while the "where/how pathway" is involved with location in space and how one might interact with a particular visual stimulus (Milner & Goodale, 2008; Ungerleider & Haxby, 1994). For example, when you see a ball rolling down the street, the "what pathway" identifies what the object is, and the "where/how pathway" identifies its location or movement in space.

COLOR AND DEPTH PERCEPTION

We do not see the world in black and white; neither do we see it as two-dimensional (2-D) or flat (just height and width, no depth). Let's look at how color vision works and how we perceive three dimensions (height, width, and depth).

Color Vision

Normal-sighted individuals have three different types of cones that mediate color vision. Each of these cone types is maximally sensitive to a slightly different wavelength of light. According to the **trichromatic theory of color vision**, shown in **Figure 5.13**, all colors in the spectrum can be produced by combining red, green, and blue. The three types of cones are each receptive to one of the colors.

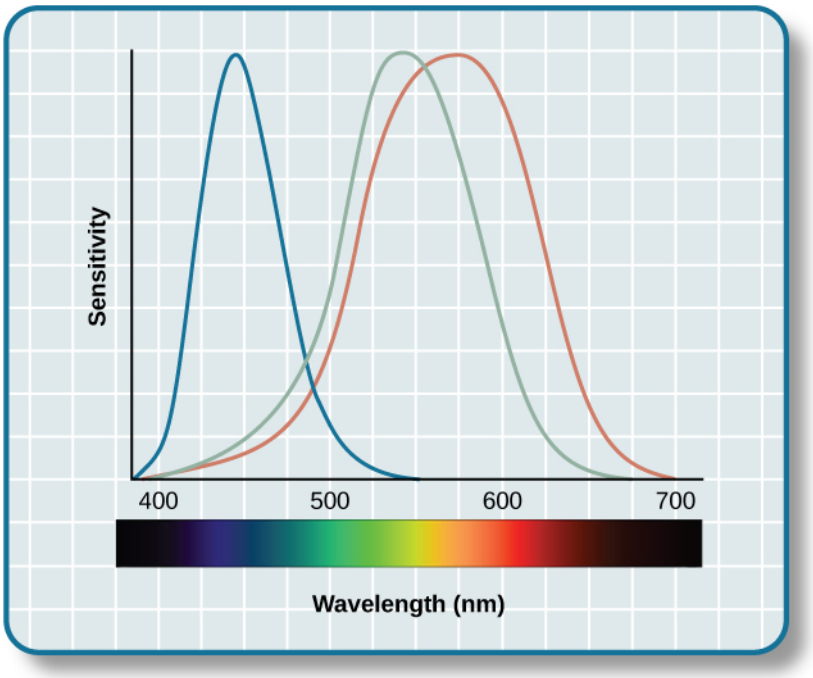

Figure 5.13 This figure illustrates the different sensitivities for the three cone types found in a normal-sighted individual. (credit: modification of work by Vanessa Ezekowitz)

The trichromatic theory of color vision is not the only theory—another major theory of color vision is known as the **opponent-process theory**. According to this theory, color is coded in opponent pairs: black-white, yellow-blue, and green-red. The basic idea is that some cells of the visual system are excited by one of the opponent colors and inhibited by the other. So, a cell that was excited by wavelengths associated with green would be inhibited by wavelengths associated with red, and vice versa. One of the implications of opponent processing is that we do not experience greenish-reds or yellowish-blues as colors. Another implication is that this leads to the experience of negative afterimages. An **afterimage** describes the continuation of a visual sensation after removal of the stimulus. For example, when you stare briefly at the sun and then look away from it, you may still perceive a spot of light although the stimulus (the sun) has been removed. When color is involved in the stimulus, the color pairings identified in the opponent-process theory lead to a negative afterimage. You can test this concept using the flag in **Figure 5.14**.

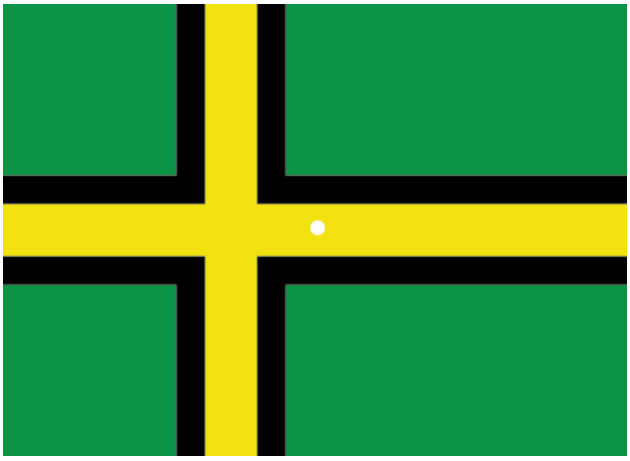

Figure 5.14 Stare at the white dot for 30–60 seconds and then move your eyes to a blank piece of white paper. What do you see? This is known as a negative afterimage, and it provides empirical support for the opponent-process theory of color vision.

But these two theories—the trichromatic theory of color vision and the opponent-process theory—are not mutually exclusive. Research has shown that they just apply to different levels of the nervous system. For visual processing on the retina, trichromatic theory applies: the cones are responsive to three different wavelengths that represent red, blue, and green. But once the signal moves past the retina on its way to the brain, the cells respond in a way consistent with opponent-process theory (Land, 1959; Kaiser, 1997).

LINK TO LEARNING

Watch this **video (http://openstaxcollege.org/l/colorvision)** to see the first part of a documentary explaining color vision in more detail.

Depth Perception

Our ability to perceive spatial relationships in three-dimensional (3-D) space is known as **depth perception**. With depth perception, we can describe things as being in front, behind, above, below, or to the side of other things.

Our world is three-dimensional, so it makes sense that our mental representation of the world has three-dimensional properties. We use a variety of cues in a visual scene to establish our sense of depth. Some of these are **binocular cues**, which means that they rely on the use of both eyes. One example of a binocular depth cue is **binocular disparity**, the slightly different view of the world that each of our eyes receives. To experience this slightly different view, do this simple exercise: extend your arm fully and extend one of your fingers and focus on that finger. Now, close your left eye without moving your head, then open your left eye and close your right eye without moving your head. You will notice that your finger seems to shift as you alternate between the two eyes because of the slightly different view each eye has of your finger.

A 3-D movie works on the same principle: the special glasses you wear allow the two slightly different images projected onto the screen to be seen separately by your left and your right eye. As your brain processes these images, you have the illusion that the leaping animal or running person is coming right toward you.

Although we rely on binocular cues to experience depth in our 3-D world, we can also perceive depth in 2-D arrays. Think about all the paintings and photographs you have seen. Generally, you pick up on depth in these images even though the visual stimulus is 2-D. When we do this, we are relying on a number of **monocular cues**, or cues that require only one eye. If you think you can't see depth with one eye, note that you don't bump into things when using only one eye while walking—and, in fact, we have more monocular cues than binocular cues.

An example of a monocular cue would be what is known as linear perspective. **Linear perspective** refers to the fact that we perceive depth when we see two parallel lines that seem to converge in an image (**Figure 5.15**). Some other monocular depth cues are interposition, the partial overlap of objects, and the relative size and closeness of images to the horizon.

Figure 5.15 We perceive depth in a two-dimensional figure like this one through the use of monocular cues like linear perspective, like the parallel lines converging as the road narrows in the distance. (credit: Marc Dalmulder)

DIG DEEPER

Stereoblindness

Bruce Bridgeman was born with an extreme case of lazy eye that resulted in him being stereoblind, or unable to respond to binocular cues of depth. He relied heavily on monocular depth cues, but he never had a true appreciation of the 3-D nature of the world around him. This all changed one night in 2012 while Bruce was seeing a movie with his wife.

The movie the couple was going to see was shot in 3-D, and even though he thought it was a waste of money, Bruce paid for the 3-D glasses when he purchased his ticket. As soon as the film began, Bruce put on the glasses and experienced something completely new. For the first time in his life he appreciated the true depth of the world around him. Remarkably, his ability to perceive depth persisted outside of the movie theater.

There are cells in the nervous system that respond to binocular depth cues. Normally, these cells require activation during early development in order to persist, so experts familiar with Bruce's case (and others like his) assume that at some point in his development, Bruce must have experienced at least a fleeting moment of binocular vision. It was enough to ensure the survival of the cells in the visual system tuned to binocular cues. The mystery now is why it took Bruce nearly 70 years to have these cells activated (Peck, 2012).

5.4 Hearing

Learning Objectives

By the end of this section, you will be able to:

- Describe the basic anatomy and function of the auditory system
- Explain how we encode and perceive pitch
- Discuss how we localize sound

Our auditory system converts pressure waves into meaningful sounds. This translates into our ability to hear the sounds of nature, to appreciate the beauty of music, and to communicate with one another through spoken language. This section will provide an overview of the basic anatomy and function of the auditory system. It will include a discussion of how the sensory stimulus is translated into neural impulses, where in the brain that information is processed, how we perceive pitch, and how we know where sound is coming from.

ANATOMY OF THE AUDITORY SYSTEM

The ear can be separated into multiple sections. The outer ear includes the **pinna**, which is the visible part of the ear that protrudes from our heads, the auditory canal, and the **tympanic membrane**, or eardrum. The middle ear contains three tiny bones known as the **ossicles**, which are named the **malleus** (or hammer), **incus** (or anvil), and the **stapes** (or stirrup). The inner ear contains the semi-circular canals, which are involved in balance and movement (the vestibular sense), and the cochlea. The **cochlea** is a fluid-filled, snail-shaped structure that contains the sensory receptor cells (hair cells) of the auditory system (**Figure 5.16**).

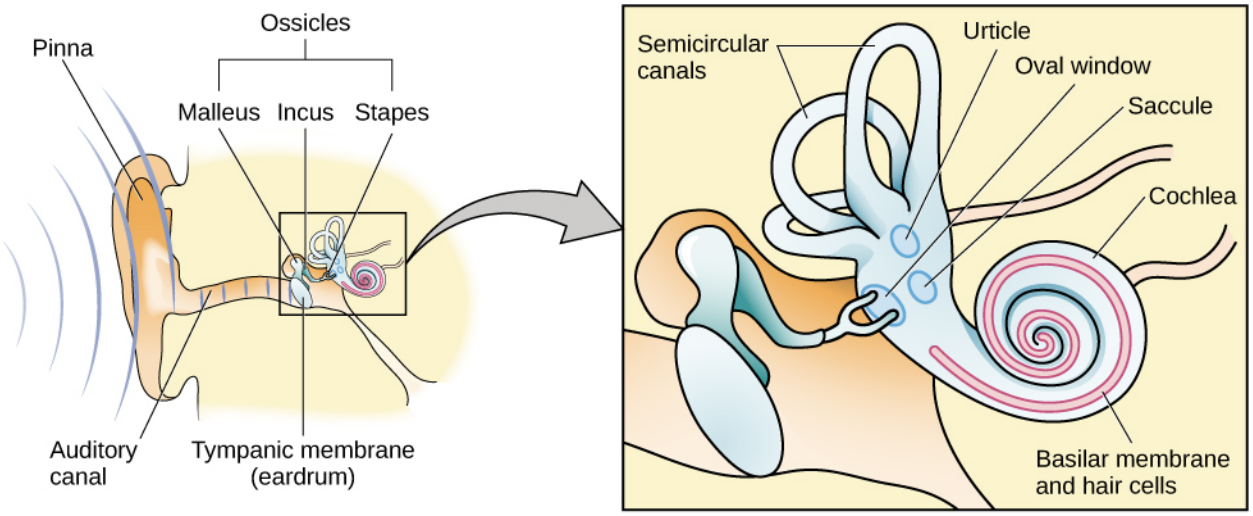

Figure 5.16 The ear is divided into outer (pinna and tympanic membrane), middle (the three ossicles: malleus, incus, and stapes), and inner (cochlea and basilar membrane) divisions.

Sound waves travel along the auditory canal and strike the tympanic membrane, causing it to vibrate. This vibration results in movement of the three ossicles. As the ossicles move, the stapes presses into a thin membrane of the cochlea known as the oval window. As the stapes presses into the oval window, the fluid inside the cochlea begins to move, which in turn stimulates **hair cells**, which are auditory receptor cells of the inner ear embedded in the basilar membrane. The **basilar membrane** is a thin strip of tissue within the cochlea.

The activation of hair cells is a mechanical process: the stimulation of the hair cell ultimately leads to activation of the cell. As hair cells become activated, they generate neural impulses that travel along the auditory nerve to the brain. Auditory information is shuttled to the inferior colliculus, the medial geniculate nucleus of the thalamus, and finally to the auditory cortex in the temporal lobe of the brain for processing. Like the visual system, there is also evidence suggesting that information about auditory recognition and localization is processed in parallel streams (Rauschecker & Tian, 2000; Renier et al., 2009).

PITCH PERCEPTION

Different frequencies of sound waves are associated with differences in our perception of the pitch of those sounds. Low-frequency sounds are lower pitched, and high-frequency sounds are higher pitched. How does the auditory system differentiate among various pitches?

Several theories have been proposed to account for pitch perception. We'll discuss two of them here: temporal theory and place theory. The **temporal theory** of pitch perception asserts that frequency is coded by the activity level of a sensory neuron. This would mean that a given hair cell would fire action potentials related to the frequency of the sound wave. While this is a very intuitive explanation, we detect such a broad range of frequencies (20–20,000 Hz) that the frequency of action potentials fired by hair cells cannot account for the entire range. Because of properties related to sodium channels on the neuronal membrane that are involved in action potentials, there is a point at which a cell cannot fire any faster (Shamma, 2001).

The **place theory** of pitch perception suggests that different portions of the basilar membrane are sensitive to sounds of different frequencies. More specifically, the base of the basilar membrane responds best to high frequencies and the tip of the basilar membrane responds best to low frequencies. Therefore, hair cells that are in the base portion would be labeled as high-pitch receptors, while those in the tip of basilar membrane would be labeled as low-pitch receptors (Shamma, 2001).

In reality, both theories explain different aspects of pitch perception. At frequencies up to about 4000 Hz, it is clear that both the rate of action potentials and place contribute to our perception of pitch. However, much higher frequency sounds can only be encoded using place cues (Shamma, 2001).

SOUND LOCALIZATION

The ability to locate sound in our environments is an important part of hearing. Localizing sound could be considered similar to the way that we perceive depth in our visual fields. Like the monocular and binocular cues that provided information about depth, the auditory system uses both **monaural** (one-eared) and **binaural** (two-eared) cues to localize sound.

Each pinna interacts with incoming sound waves differently, depending on the sound's source relative to our bodies. This interaction provides a monaural cue that is helpful in locating sounds that occur above or below and in front or behind us. The sound waves received by your two ears from sounds that come from directly above, below, in front, or behind you would be identical; therefore, monaural cues are essential (Grothe, Pecka, & McAlpine, 2010).

Binaural cues, on the other hand, provide information on the location of a sound along a horizontal axis by relying on differences in patterns of vibration of the eardrum between our two ears. If a sound comes from an off-center location, it creates two types of binaural cues: interaural level differences and interaural timing differences. **Interaural level difference** refers to the fact that a sound coming from the right side of your body is more intense at your right ear than at your left ear because of the attenuation of the sound wave as it passes through your head. **Interaural timing difference** refers to the small difference in the time at which a given sound wave arrives at each ear (**Figure 5.17**). Certain brain areas monitor these differences to construct where along a horizontal axis a sound originates (Grothe et al., 2010).

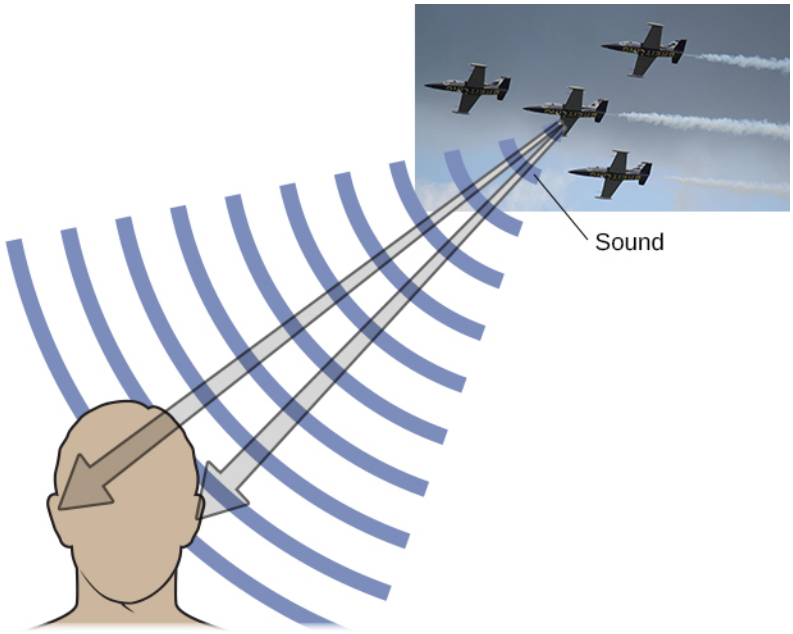

Figure 5.17 Localizing sound involves the use of both monaural and binaural cues. (credit "plane": modification of work by Max Pfandl)

HEARING LOSS

Deafness is the partial or complete inability to hear. Some people are born deaf, which is known as **congenital deafness**. Many others begin to suffer from **conductive hearing loss** because of age, genetic predisposition, or environmental effects, including exposure to extreme noise (noise-induced hearing loss, as shown in **Figure 5.18**), certain illnesses (such as measles or mumps), or damage due to toxins (such as those found in certain solvents and metals).

Figure 5.18 Environmental factors that can lead to conductive hearing loss include regular exposure to loud music or construction equipment. (a) Rock musicians and (b) construction workers are at risk for this type of hearing loss. (credit a: modification of work by Kenny Sun; credit b: modification of work by Nick Allen)

Given the mechanical nature by which the sound wave stimulus is transmitted from the eardrum through the ossicles to the oval window of the cochlea, some degree of hearing loss is inevitable. With conductive hearing loss, hearing problems are associated with a failure in the vibration of the eardrum and/or movement of the ossicles. These problems are often dealt with through devices like hearing aids that

amplify incoming sound waves to make vibration of the eardrum and movement of the ossicles more likely to occur.

When the hearing problem is associated with a failure to transmit neural signals from the cochlea to the brain, it is called **sensorineural hearing loss**. One disease that results in sensorineural hearing loss is **Ménière's disease**. Although not well understood, Ménière's disease results in a degeneration of inner ear structures that can lead to hearing loss, tinnitus (constant ringing or buzzing), **vertigo** (a sense of spinning), and an increase in pressure within the inner ear (Semaan & Megerian, 2011). This kind of loss cannot be treated with hearing aids, but some individuals might be candidates for a cochlear implant as a treatment option. **Cochlear implants** are electronic devices that consist of a microphone, a speech processor, and an electrode array. The device receives incoming sound information and directly stimulates the auditory nerve to transmit information to the brain.

LINK TO LEARNING

Watch this **video (http://www.youtube.com/watch?v=AqXBrKwB96E)** describe cochlear implant surgeries and how they work.

WHAT DO YOU THINK?

Deaf Culture

In the United States and other places around the world, deaf people have their own language, schools, and customs. This is called deaf culture. In the United States, deaf individuals often communicate using American Sign Language (ASL); ASL has no verbal component and is based entirely on visual signs and gestures. The primary mode of communication is signing. One of the values of deaf culture is to continue traditions like using sign language rather than teaching deaf children to try to speak, read lips, or have cochlear implant surgery.

When a child is diagnosed as deaf, parents have difficult decisions to make. Should the child be enrolled in mainstream schools and taught to verbalize and read lips? Or should the child be sent to a school for deaf children to learn ASL and have significant exposure to deaf culture? Do you think there might be differences in the way that parents approach these decisions depending on whether or not they are also deaf?

5.5 The Other Senses

Learning Objectives

By the end of this section, you will be able to:

- Describe the basic functions of the chemical senses
- Explain the basic functions of the somatosensory, nociceptive, and thermoceptive sensory systems
- Describe the basic functions of the vestibular, proprioceptive, and kinesthetic sensory systems

Vision and hearing have received an incredible amount of attention from researchers over the years. While there is still much to be learned about how these sensory systems work, we have a much better

understanding of them than of our other sensory modalities. In this section, we will explore our chemical senses (taste and smell) and our body senses (touch, temperature, pain, balance, and body position).

THE CHEMICAL SENSES

Taste (gustation) and smell (olfaction) are called chemical senses because both have sensory receptors that respond to molecules in the food we eat or in the air we breathe. There is a pronounced interaction between our chemical senses. For example, when we describe the flavor of a given food, we are really referring to both gustatory and olfactory properties of the food working in combination.

Taste (Gustation)

You have learned since elementary school that there are four basic groupings of taste: sweet, salty, sour, and bitter. Research demonstrates, however, that we have at least six taste groupings. Umami is our fifth taste. **Umami** is actually a Japanese word that roughly translates to yummy, and it is associated with a taste for monosodium glutamate (Kinnamon & Vandenbeuch, 2009). There is also a growing body of experimental evidence suggesting that we possess a taste for the fatty content of a given food (Mizushige, Inoue, & Fushiki, 2007).

Molecules from the food and beverages we consume dissolve in our saliva and interact with taste receptors on our tongue and in our mouth and throat. **Taste buds** are formed by groupings of taste receptor cells with hair-like extensions that protrude into the central pore of the taste bud (**Figure 5.19**). Taste buds have a life cycle of ten days to two weeks, so even destroying some by burning your tongue won't have any long-term effect; they just grow right back. Taste molecules bind to receptors on this extension and cause chemical changes within the sensory cell that result in neural impulses being transmitted to the brain via different nerves, depending on where the receptor is located. Taste information is transmitted to the medulla, thalamus, and limbic system, and to the gustatory cortex, which is tucked underneath the overlap between the frontal and temporal lobes (Maffei, Haley, & Fontanini, 2012; Roper, 2013).

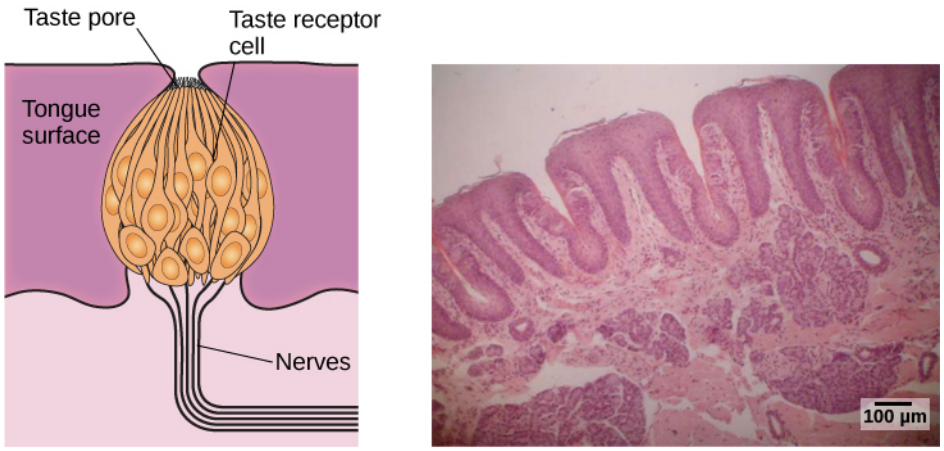

Figure 5.19 (a) Taste buds are composed of a number of individual taste receptors cells that transmit information to nerves. (b) This micrograph shows a close-up view of the tongue's surface. (credit a: modification of work by Jonas Töle; credit b: scale-bar data from Matt Russell)

Smell (Olfaction)

Olfactory receptor cells are located in a mucous membrane at the top of the nose. Small hair-like extensions from these receptors serve as the sites for odor molecules dissolved in the mucus to interact with chemical receptors located on these extensions (**Figure 5.20**). Once an odor molecule has bound a

given receptor, chemical changes within the cell result in signals being sent to the **olfactory bulb**: a bulb-like structure at the tip of the frontal lobe where the olfactory nerves begin. From the olfactory bulb, information is sent to regions of the limbic system and to the primary olfactory cortex, which is located very near the gustatory cortex (Lodovichi & Belluscio, 2012; Spors et al., 2013).

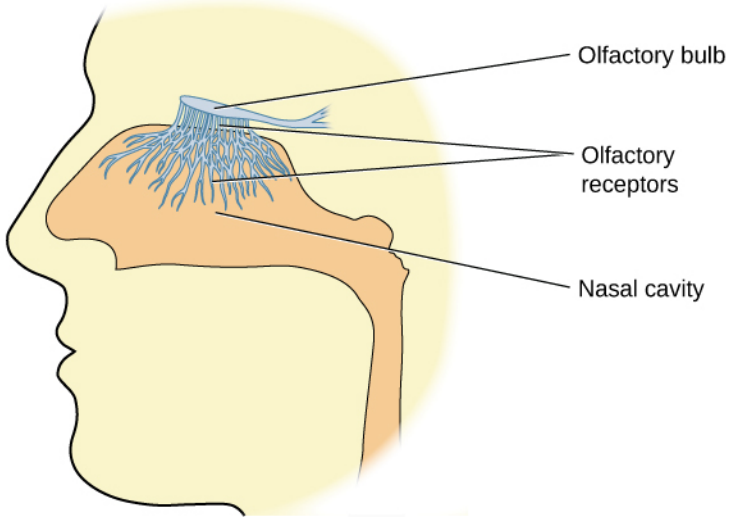

Figure 5.20 Olfactory receptors are the hair-like parts that extend from the olfactory bulb into the mucous membrane of the nasal cavity.

There is tremendous variation in the sensitivity of the olfactory systems of different species. We often think of dogs as having far superior olfactory systems than our own, and indeed, dogs can do some remarkable things with their noses. There is some evidence to suggest that dogs can "smell" dangerous drops in blood glucose levels as well as cancerous tumors (Wells, 2010). Dogs' extraordinary olfactory abilities may be due to the increased number of functional genes for olfactory receptors (between 800 and 1200), compared to the fewer than 400 observed in humans and other primates (Niimura & Nei, 2007).

Many species respond to chemical messages, known as **pheromones**, sent by another individual (Wysocki & Preti, 2004). Pheromonal communication often involves providing information about the reproductive status of a potential mate. So, for example, when a female rat is ready to mate, she secretes pheromonal signals that draw attention from nearby male rats. Pheromonal activation is actually an important component in eliciting sexual behavior in the male rat (Furlow, 1996, 2012; Purvis & Haynes, 1972; Sachs, 1997). There has also been a good deal of research (and controversy) about pheromones in humans (Comfort, 1971; Russell, 1976; Wolfgang-Kimball, 1992; Weller, 1998).

TOUCH, THERMOCEPTION, AND NOCICEPTION

A number of receptors are distributed throughout the skin to respond to various touch-related stimuli (**Figure 5.21**). These receptors include Meissner's corpuscles, Pacinian corpuscles, Merkel's disks, and Ruffini corpuscles.**Meissner's corpuscles** respond to pressure and lower frequency vibrations, and **Pacinian corpuscles** detect transient pressure and higher frequency vibrations. **Merkel's disks** respond to light pressure, while **Ruffini corpuscles** detect stretch (Abraira & Ginty, 2013).

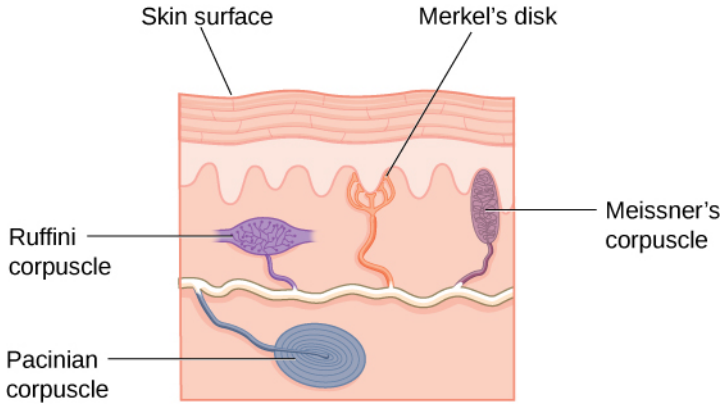

Figure 5.21 There are many types of sensory receptors located in the skin, each attuned to specific touch-related stimuli.

In addition to the receptors located in the skin, there are also a number of free nerve endings that serve sensory functions. These nerve endings respond to a variety of different types of touch-related stimuli and serve as sensory receptors for both **thermoception** (temperature perception) and **nociception** (a signal indicating potential harm and maybe pain) (Garland, 2012; Petho & Reeh, 2012; Spray, 1986). Sensory information collected from the receptors and free nerve endings travels up the spinal cord and is transmitted to regions of the medulla, thalamus, and ultimately to somatosensory cortex, which is located in the postcentral gyrus of the parietal lobe.

Pain Perception

Pain is an unpleasant experience that involves both physical and psychological components. Feeling pain is quite adaptive because it makes us aware of an injury, and it motivates us to remove ourselves from the cause of that injury. In addition, pain also makes us less likely to suffer additional injury because we will be gentler with our injured body parts.

Generally speaking, pain can be considered to be neuropathic or inflammatory in nature. Pain that signals some type of tissue damage is known as **inflammatory pain**. In some situations, pain results from damage to neurons of either the peripheral or central nervous system. As a result, pain signals that are sent to the brain get exaggerated. This type of pain is known as **neuropathic pain**. Multiple treatment options for pain relief range from relaxation therapy to the use of analgesic medications to deep brain stimulation. The most effective treatment option for a given individual will depend on a number of considerations, including the severity and persistence of the pain and any medical/psychological conditions.

Some individuals are born without the ability to feel pain. This very rare genetic disorder is known as **congenital insensitivity to pain** (or **congenital analgesia**). While those with congenital analgesia can detect differences in temperature and pressure, they cannot experience pain. As a result, they often suffer significant injuries. Young children have serious mouth and tongue injuries because they have bitten themselves repeatedly. Not surprisingly, individuals suffering from this disorder have much shorter life expectancies due to their injuries and secondary infections of injured sites (U.S. National Library of Medicine, 2013).

This content is available for free at http://legacy.cnx.org/content/col11629/1.4

LINK TO LEARNING

Watch this **video (http://openstaxcollege.org/l/congenital)** to learn more about congenital insensitivity to pain.

THE VESTIBULAR SENSE, PROPRIOCEPTION, AND KINESTHESIA

The **vestibular sense** contributes to our ability to maintain balance and body posture. As **Figure 5.22** shows, the major sensory organs (utricle, saccule, and the three semicircular canals) of this system are located next to the cochlea in the inner ear. The vestibular organs are fluid-filled and have hair cells, similar to the ones found in the auditory system, which respond to movement of the head and gravitational forces. When these hair cells are stimulated, they send signals to the brain via the vestibular nerve. Although we may not be consciously aware of our vestibular system's sensory information under normal circumstances, its importance is apparent when we experience motion sickness and/or dizziness related to infections of the inner ear (Khan & Chang, 2013).

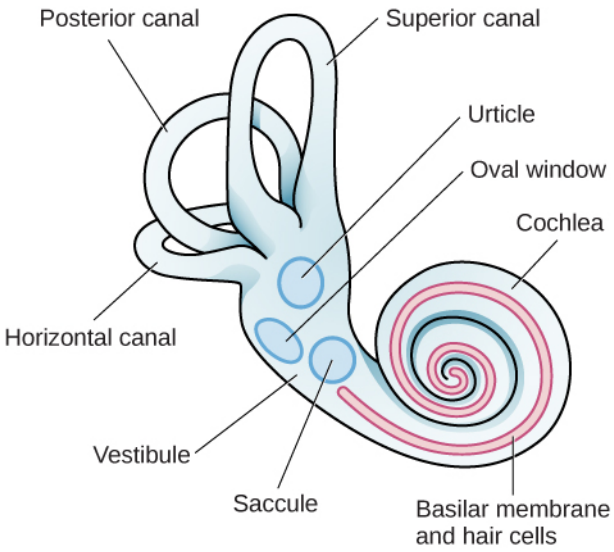

Figure 5.22 The major sensory organs of the vestibular system are located next to the cochlea in the inner ear. These include the utricle, saccule, and the three semicircular canals (posterior, superior, and horizontal).

In addition to maintaining balance, the vestibular system collects information critical for controlling movement and the reflexes that move various parts of our bodies to compensate for changes in body position. Therefore, both **proprioception** (perception of body position) and **kinesthesia** (perception of the body's movement through space) interact with information provided by the vestibular system.

These sensory systems also gather information from receptors that respond to stretch and tension in muscles, joints, skin, and tendons (Lackner & DiZio, 2005; Proske, 2006; Proske & Gandevia, 2012). Proprioceptive and kinesthetic information travels to the brain via the spinal column. Several cortical regions in addition to the cerebellum receive information from and send information to the sensory organs of the proprioceptive and kinesthetic systems.

5.6 Gestalt Principles of Perception

Learning Objectives

By the end of this section, you will be able to:

- Explain the figure-ground relationship
- Define Gestalt principles of grouping
- Describe how perceptual set is influenced by an individual's characteristics and mental state

In the early part of the 20th century, Max Wertheimer published a paper demonstrating that individuals perceived motion in rapidly flickering static images—an insight that came to him as he used a child's toy tachistoscope. Wertheimer, and his assistants Wolfgang Köhler and Kurt Koffka, who later became his partners, believed that perception involved more than simply combining sensory stimuli. This belief led to a new movement within the field of psychology known as **Gestalt psychology**. The word *gestalt* literally means form or pattern, but its use reflects the idea that the whole is different from the sum of its parts. In other words, the brain creates a perception that is more than simply the sum of available sensory inputs, and it does so in predictable ways. Gestalt psychologists translated these predictable ways into principles by which we organize sensory information. As a result, Gestalt psychology has been extremely influential in the area of sensation and perception (Rock & Palmer, 1990).

One Gestalt principle is the **figure-ground relationship**. According to this principle, we tend to segment our visual world into figure and ground. Figure is the object or person that is the focus of the visual field, while the ground is the background. As **Figure 5.23** shows, our perception can vary tremendously, depending on what is perceived as figure and what is perceived as ground. Presumably, our ability to interpret sensory information depends on what we label as figure and what we label as ground in any particular case, although this assumption has been called into question (Peterson & Gibson, 1994; Vecera & O'Reilly, 1998).

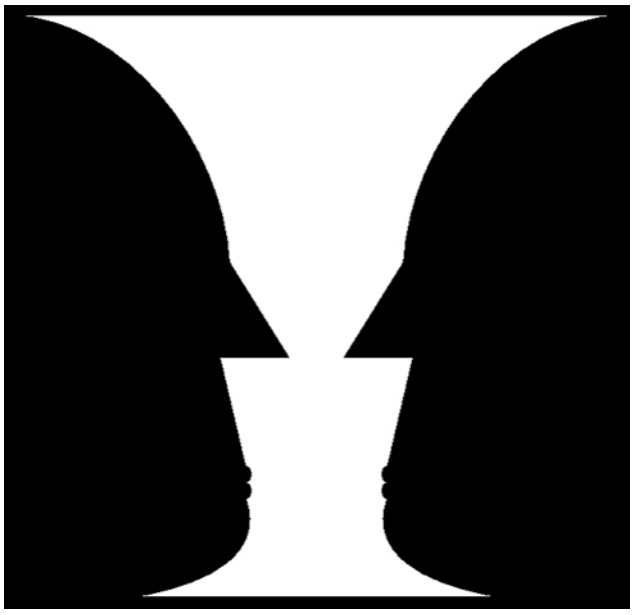

Figure 5.23 The concept of figure-ground relationship explains why this image can be perceived either as a vase or as a pair of faces.

Another Gestalt principle for organizing sensory stimuli into meaningful perception is **proximity**. This principle asserts that things that are close to one another tend to be grouped together, as **Figure 5.24** illustrates.

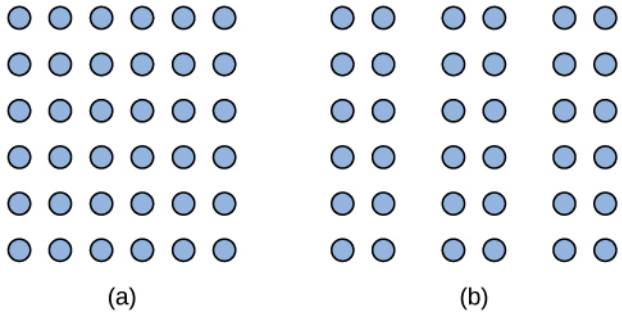

Figure 5.24 The Gestalt principle of proximity suggests that you see (a) one block of dots on the left side and (b) three columns on the right side.

How we read something provides another illustration of the proximity concept. For example, we read this sentence like this, notl iket hiso rt hat. We group the letters of a given word together because there are no spaces between the letters, and we perceive words because there are spaces between each word. Here are some more examples: Cany oum akes enseo ft hiss entence? What doth es e wor dsmea n?

We might also use the principle of **similarity** to group things in our visual fields. According to this principle, things that are alike tend to be grouped together (**Figure 5.25**). For example, when watching a football game, we tend to group individuals based on the colors of their uniforms. When watching an offensive drive, we can get a sense of the two teams simply by grouping along this dimension.

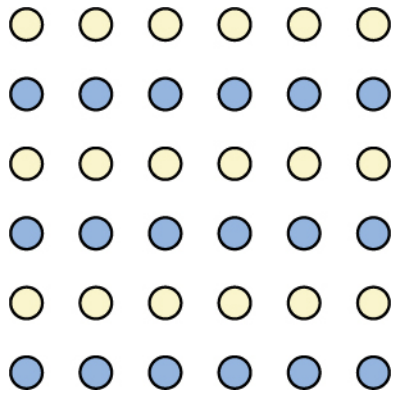

Figure 5.25 When looking at this array of dots, we likely perceive alternating rows of colors. We are grouping these dots according to the principle of similarity.

Two additional Gestalt principles are the law of **continuity** (or **good continuation**) and **closure**. The law of continuity suggests that we are more likely to perceive continuous, smooth flowing lines rather than jagged, broken lines (**Figure 5.26**). The **principle of closure** states that we organize our perceptions into complete objects rather than as a series of parts (**Figure 5.27**).

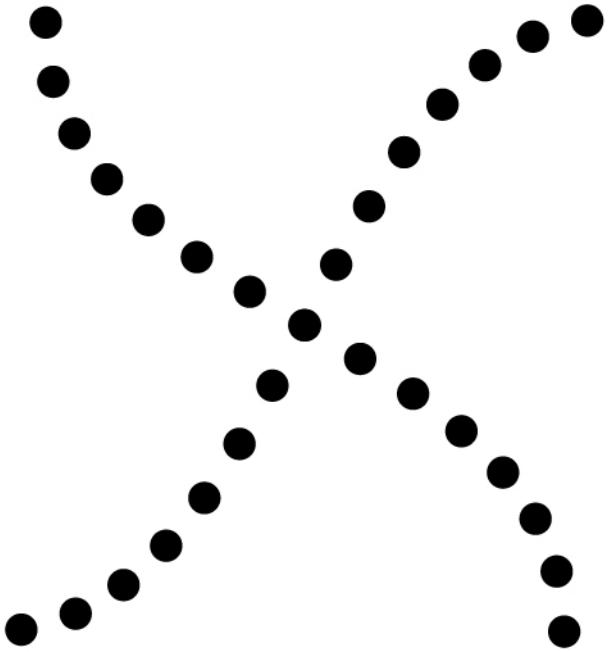

Figure 5.26 Good continuation would suggest that we are more likely to perceive this as two overlapping lines, rather than four lines meeting in the center.

Figure 5.27 Closure suggests that we will perceive a complete circle and rectangle rather than a series of segments.

LINK TO LEARNING

Watch this **video (http://openstaxcollege.org/l/gestalt)** showing real world illustrations of Gestalt principles.

According to Gestalt theorists, **pattern perception**, or our ability to discriminate among different figures and shapes, occurs by following the principles described above. You probably feel fairly certain that your perception accurately matches the real world, but this is not always the case. Our perceptions are based on **perceptual hypotheses**: educated guesses that we make while interpreting sensory information. These hypotheses are informed by a number of factors, including our personalities, experiences, and expectations. We use these hypotheses to generate our perceptual set. For instance, research has demonstrated that those who are given verbal priming produce a biased interpretation of complex ambiguous figures (Goolkasian & Woodbury, 2010).

DIG DEEPER

The Depths of Perception: Bias, Prejudice, and Cultural Factors

In this chapter, you have learned that perception is a complex process. Built from sensations, but influenced by our own experiences, biases, prejudices, and cultures, perceptions can be very different from person to person. Research suggests that implicit racial prejudice and stereotypes affect perception. For instance, several studies have demonstrated that non-Black participants identify weapons faster and are more likely to identify non-weapons as weapons when the image of the weapon is paired with the image of a Black person (Payne, 2001; Payne, Shimizu, & Jacoby, 2005). Furthermore, White individuals' decisions to shoot an armed target in a video game is made more quickly when the target is Black (Correll, Park, Judd, & Wittenbrink, 2002; Correll, Urland, & Ito, 2006). This research is important, considering the number of very high-profile cases in the last few decades in which young Blacks were killed by people who claimed to believe that the unarmed individuals were armed and/or represented some threat to their personal safety.